UIUCDCS-R-72-508

COO-1469-0202

# HARDWARE/SOFTWARE INTERFACE FOR THE STEREOMATRIX DISPLAY

by

Ian MacDonald Cunningham

June 1972

DEPARTMENT OF COMPUTER SCIENCE
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN · URBANA, ILLINOIS

UIUCDCS-R-72-508

# HARDWARE/SOFTWARE INTERFACE FOR THE STEREOMATRIX DISPLAY*

by

Ian MacDonald Cunningham

June 1972

DEPARTMENT OF COMPUTER SCIENCE
UNIVERSITY OF ILLINOIS
URBANA, ILLINOIS 61801

* Supported in part by the Department of Computer Science and the Atomic Energy Commission under contract US AEC AT(11-1)1469, and submitted in partial fulfillment of the requirements of the Graduate College for the degree of Master of Science in Computer Science.

## ACKNOWLEDGMENT

I would like to thank my advisor, Professor C. W. Gear, for his support, Miss Barbara Hurdle for her typing, and Mr. Harold Lopeman for his excellent work in constructing the interface. I would also like to thank Professor W. J. Poppelbaum, the principal investigator for the Stereomatrix; and Professor W. J. Kubitz, Mr. Shiv Verma, Mr. Steve Whiteside, and Mr. Chuck Pirnat for their assistance. My wife deserves many thanks for both her assistance and understanding.

TABLE OF CONTENTS

# LIST OF FIGURES

# 1. INTRODUCTION

A random access, three-dimensional laser display called Stereomatrix has been built by a group in the Department of Computer Science at the University of Illinois [1]. Three-dimensional wire figures are displayed by generating separate images for the left and right eyes. The light from the laser is split into two beams, and then the polarization of the left beam is rotated 90 degrees. Both beams are deflected along the x and y axis, resulting in a double image. The observer wears glasses with oppositely polarized lenses which give the visual effect of a third dimension. The observer's position is sensed by an infrared light source contained on the glasses. Movements of the observer are detected and automatic re-displaying of the figure as it would appear to the observer from the new position occurs. The observer also may scale, rotate, and translate the picture under complete hardware control. A three-dimensional cursor is also displayed by the hardware which permits initializing of points in space and identifying lines that already appear on the screen.

Wire figures for the display are supplied by either PAGAN [2], a hardware generator of geometric figures, or by a PDP-8/I computer. The design of the latter's interface and programming system is described in the report.

## 2. SYSTEM OVERVIEW

A block diagram of the Stereomatrix-PDP-8/I graphics system is shown in Figure 1. The Stereomatrix display can be divided into four subsections: laser and deflecting optics, position sensor, coefficient generator, and transformer.

The light source is a 2 watt argon laser. Acoustical deflectors and lenses are used to position and focus the beam on the rear of the screen. Beam positioning is random access, requiring a constant 6.8 microseconds to move to any point on the screen ($1.5 \times 10^5$ points/second).

The position sensors continually monitor the infrared light source on the observer's glasses. The two angles supplied by these sensors plus the distance between them are sufficient for calculating the observer's location.

The coefficient generator controls rotation, translation, and scaling of the figure. The generator is controlled directly by several switches which allow selection of one of the above operations plus axis and direction and a reset button to return the figure to its initial position.

The transformer receives the figure from the computer in digital form and converts it to analog. The output of the coefficient generator, which is a matrix, is used by the transformer to modify the figure as requested by the user. The figure is then modified again using the data from the position sensors, creating the final two perspective drawings. All operations are performed digitally by the coefficient generator, but the calculation rate of the transformer requires that the calculation be performed on analog values.

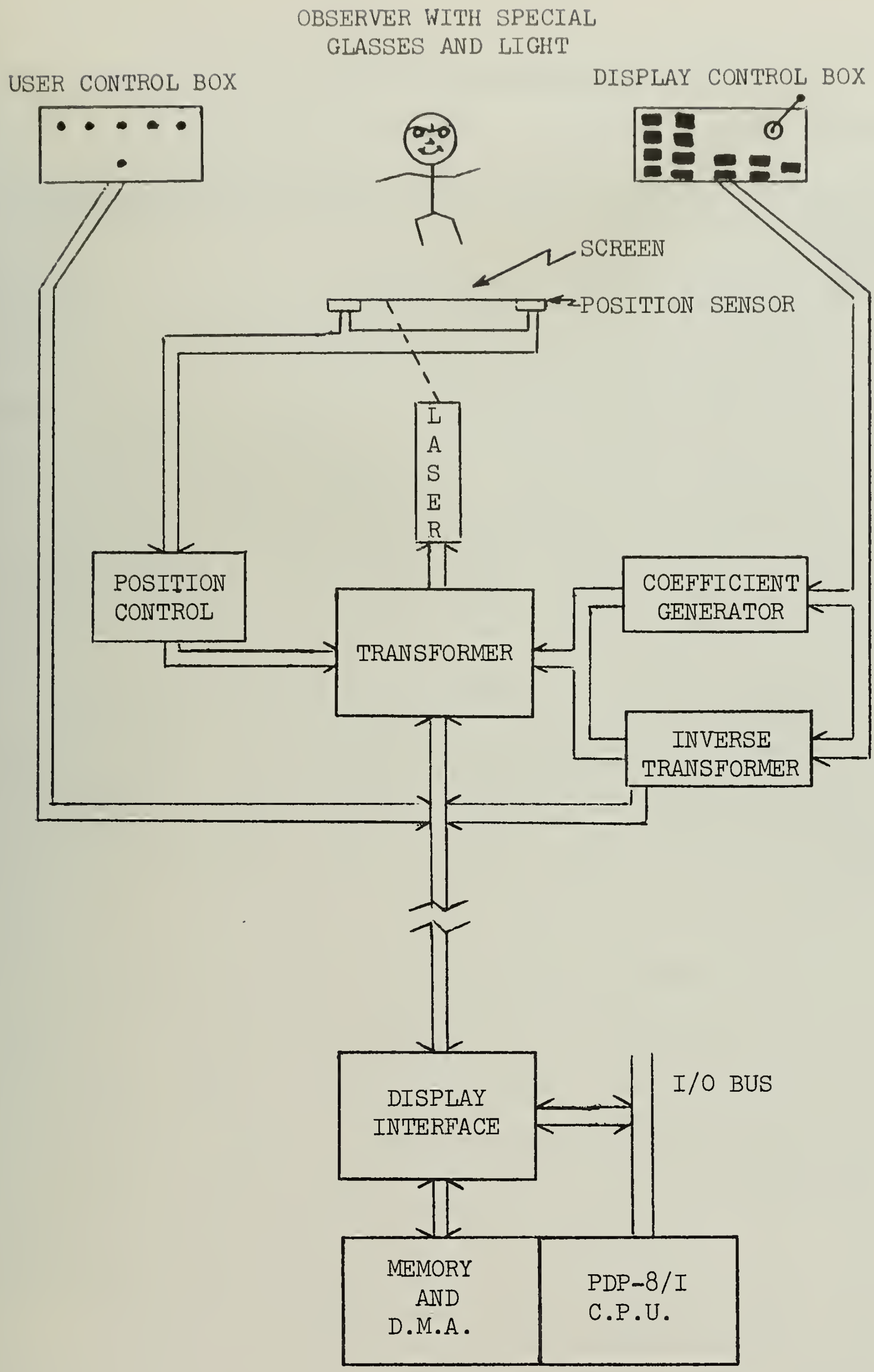



Figure 1. Stereomatrix Display System

A hardware cursor is also incorporated in the display. An inverse transformer converts the cursors co-ordinates from the observer's space to computer space before transmitting them back to the interface.

The transfer of data between the display and the interface utilizes both digital and analog signals. The PDP-8/I generates display files for the interface which then transmits a sequence of three-dimensional co-ordinates. The display interface and computer transfer control information using the PDP-8/I I/O bus, and the interface accesses the display files using the Direct Memory Access (DMA).

The display and the computer are approximately 200 feet apart. The interface and communication controls operate asynchronously with a maximum data rate of approximately $2.5 \times 10^6$ co-ordinates per second.

# 3. HARDWARE INTERFACE

## 3.1 Design Philosophy

The project was motivated by a need to test the Stereomatrix display and to study user requirements in a three-dimensional graphic environment, and not the development of a new or novel computer/display interface. In order to design and implement a total graphics system within a reasonable time limit, some hardware compromises have to be made. For example, a hardware line generator, while common in most sophisticated displays, was not included. Direct program manipulation of the three co-ordinate registers would reduce the usable computing power of the machine and would not exceed the minimum transmission rate. As a result, a line generator of limited directional powers was implemented. A line of up to 63 points is generated in one of twenty-seven directions. This is done by controlling the increment for each axis to -1, 0, or +1. These directions plus two control modes are encoded into five bits of a display command. Another bit is reserved for the intensity (ON/OFF) and the remaining six bits are either display status or length information. Direct branches and subroutine calls, often embedded in the display file, were implemented in the graphics syntactic data structure, resulting in considerable simplification in the control.

All data is transmitted as digital signals (except cursor co-ordinates) which exist at the display as analog values. Asynchronous circuits control both the interface and the transmission of co-ordinates to the display. As a result, any increase in the plotting rate of the display (presently limited by laser optics) will automatically increase the speed of the interface.

Four flags generate interrupts. One is set by the interface upon completion of a display file while the other three are set at the display by

1. the user control box switches,
2. the cursor position interrupt switch, or
3. by the incidence of a displayed line with the cursor.

## 3.2 Programming the Interface

The computer must transmit a sequence of points that will represent the desired graphic image when it is displayed. Because the display does not have its own memory and the image is not stored on the screen, this process must occur continually. The display interface uses the PDP-8/I I/O bus to initialize registers, start hardware sequences, and notify the software of interrupt conditions. The direct memory access facility, DMA, fetches information sequentially from the computer's main memory. This data is used to generate the sequences of co-ordinates. Conceptually, the interface can be broken into three sections: picture generation, cursor co-ordinates, and interrupts and miscellaneous controls. The following discussion defines and explains the usage of all interface instructions. Appendix A lists all instructions, their mnemonics, and their octal value.

### Picture Generation

The X, Y, and Z co-ordinate registers which position the laser beam are initialized by direct transfers from the accumulator. The 10-bit values are left justified and expressed in sign and magnitude notation. The left most bit is a "1" for negative values.

The load instructions LDX (LoaD X), LDY, and LDZ transfer the contents of the accumulator to the X, Y, and Z co-ordinate registers, respectively. The contents of the accumulator (AC) remain unchanged and the two low-order bits are ignored.

With this initialization completed, the memory address of the display file for the DMA is transferred to the interface and the display started. The program code is

```
CLA          /  CLEAR AC
TAD  ADRES   /  ADDRESS OF DISPLAY FILE
DSPRGO       /  START DISPLAY
```

The instruction DSPRGO (DiSPlay Reset and Go) is the OR of the two display instructions STPDSP (SToP DiSPlay) and DRAW. STPDSP forces the interface logic into the halt state if it has not already been entered and the display completed flag is cleared.

Next, DRAW transfers the contents of the AC to the DMA address register in the interface and starts the display. Note that the contents of the address register are unchanged by the STPDSP instruction.

The display file referenced by DSPRGO must contain one or more single word display commands. The format for the three types of commands is in Figure 2. A typical display file contains a load status command followed by a number of line commands and completed with a halt. The halt command sets the display completed flag which results in a program interrupt. SKDF (SKip on Display File done) tests this flag. Another display file may be initiated without re-initializing the co-ordinate or display status registers since they are not affected by the halt command. Lines which exceed the limit of the screen are

Load Status Command

A, B, and C fields are loaded into display status register.

| Bit | 0 | 1 – 5 | 6 – 7 | 8 – 9 | 10 – 11 |
|---|---|---|---|---|---|
| | ☒ | $36_8$ | A | B | C |

A: Scale 00 Every point
01 Every 2nd point
10 Every 3rd point
11 Every 4th point

B: Free bits for future use

C: Brightness proportional to value, i.e. 11 is brightest

Line Command

Plots a line in 1 of 27 directions and up to 63 scaled points in length.

| Bit | 0 | 1 – 5 | 6 – 11 |
|---|---|---|---|
| | I | DIRECTION | LENGTH |

I: Line is intensified if bit is "1"

DIRECTION: Value is ((Z*3) + Y) * 3 + X where

X, Y, Z = 0 if no axial component
= 1 for positive increment
= 2 for negative increment

LENGTH: Length of line before modified by scale

Halt Command

Picture generation is stopped and display flag is set.

| Bit | 0 | 1 – 5 | 6 – 11 |
|---|---|---|---|
| | ☒ | $37_8$ | ☒ |

Figure 2. Display Command Formats

wrapped around by the interface and no interrupt is generated. A co-ordinate register value of +511 when incremented becomes -511.

Cursor Co-ordinates

The current position of the cursor is always held in a buffer in the interface and is accessed by the instructions RDX (ReaD X cursor co-ordinates), RDY, and RDZ. The accumulator is automatically cleared before the co-ordinate value is transferred to the AC. The value is expressed in 10 bits, left justified 2's complement notation.

Display Interrupts and Miscellaneous Controls

Three additional registers are of interest to the programmer: the memory address extension register, the switch register, and the interrupt register. The first contains the extended address bits required by the DMA. It is loaded along with the interrupt register which is discussed below.

The switch register holds the output from the five switches on the user control box. This register is OR'ed into the AC and then cleared by the REDBX (REaD BoX) instruction. Depressing switch i ($1 \leq i \leq 5$) will result in AC bit 12 - i being a "1" upon completion of this instruction. The sixth switch on the user box (marked "I") sets a bit in the interrupt register.

The interrupt register holds the cursor, incidence, and switch register flags. If the OR of these flags is "1", a program interrupt occurs. SKBF (SKip on Buffered Flags) tests for this condition. In order to determine which flags are set, this register

is OR'ed into the AC by the RDFLG (ReaD FLaGs) instruction. The specific bit meanings are shown in Figure 3a. The CLRFLG (CLeaR FLaGs) instruction both resets flags in the interrupt register and loads the memory address extension register. The format of the AC bits is shown in Figure 3b. A flag is cleared only if the corresponding bit was a "1". When servicing an interrupt, it is advisable to clear only the one flag as the others may have been subsequently set and a loss of the interrupt will occur. Both the cursor and switch register flags, unlike incidence, notify the program that action is required, but do not stop picture generation.

The incidence flag is set only after the incidence mode has been enabled in the display and the cursor is "near" to a line drawn by the computer. When this flag is set, the RUN flip-flop in the interface is cleared, causing picture generation to cease. The RDCMA (ReaD Complement of Memory Address) instruction OR's the logical complement of the memory address used by the DMA into the AC. This address is normally one more than the address of the display command plotting the point, but it may be two more due to look-ahead in both the display and interface controls. Upon completion of any processing, the display may be continued without loss of information by the RESUM (RESUMe) instruction. The AC is not used.

| Bit | 0 | 1 | 2 | |
|---|---|---|---|---|
| | F0 | F1 | F2 | |

Figure 3a. Accumulator bits for RDFLG instruction

| Bit | 0 | 1 | 2 | | 9 11 |
|---|---|---|---|---|---|
| | F0 | F1 | F2 | | MEA |

Figure 3b. Accumulator bits for CLRFLG instruction

F0: Cursor Position Interrupt

F1: Cursor Incidence Interrupt

F2: User Control Box Interrupt

MEA: Memory Address Extension for DMA

Figure 3. Interrupt and Address Extension Registers

### 3.3 Overview of Hardware Logic

A block diagram of the Stereomatrix interface in Figure 4 includes both the major cards with their functions and major control signals contained in the interface. Each of the rectangles represents one card (except Accumulator In). In order to simplify both construction and maintenance of the interface, identical cards were designed where possible. Consequently, 13 cards of the interface represent only four designs.

The Sequencer which is the heart of the picture generating process requests data by sending BRK1 to the DMA control card. It handles the transfer of display commands from the computer's memory and the incrementing of the memory address register. The Sequencer proceeds upon receipt of the NODAT signal. The Direction Decoder deciphers the command field. The halt command stops the Sequencer and interrupts the processor while the status command gates the length

register into the display status register and BRK1 is set again for more data. If neither of these commands occur, the Sequencer waits for a data request from the display (LREQ) and then responds with LDATGO level. The co-ordinate registers are up/down sign and magnitude binary counters. The COUNT pulse from the Sequencer updates these registers based upon inputs from the Direction Decoder which specifies +1, 0, or -1 increments. From one to four COUNT pulses, depending upon the scale in the display status register, are generated by the Sequencer. The length of the line which is stored in the DMA Control card is monitored by the Sequencer and decremented after each new co-ordinate is accepted by the display. When the length becomes zero, the Sequencer requests another display command from memory. If the intensity bit in the line commands is OFF, the Sequencer operates at its maximum rate of approximately 400 ns. per register increment. The Sequencer and DMA control run asynchronously except for one state responsible for clocking the co-ordinate registers. The algorithm is discussed in more detail in the next section and the logic drawing is in Appendix B.

Five cables each transmit 10 digital signals between the interface and the display. This high speed data transmission system utilizes balanced, terminated, twisted pair lines. This method has high common-mode noise rejection.

The three A/D converters, one for each cursor co-ordinate, are controlled by a signal (not shown) from the display. Upon completion of a conversion, the results are stored in the A/D Data Buffer. Consequently, cursor co-ordinate values are available to the program while another A/D conversion is being performed.

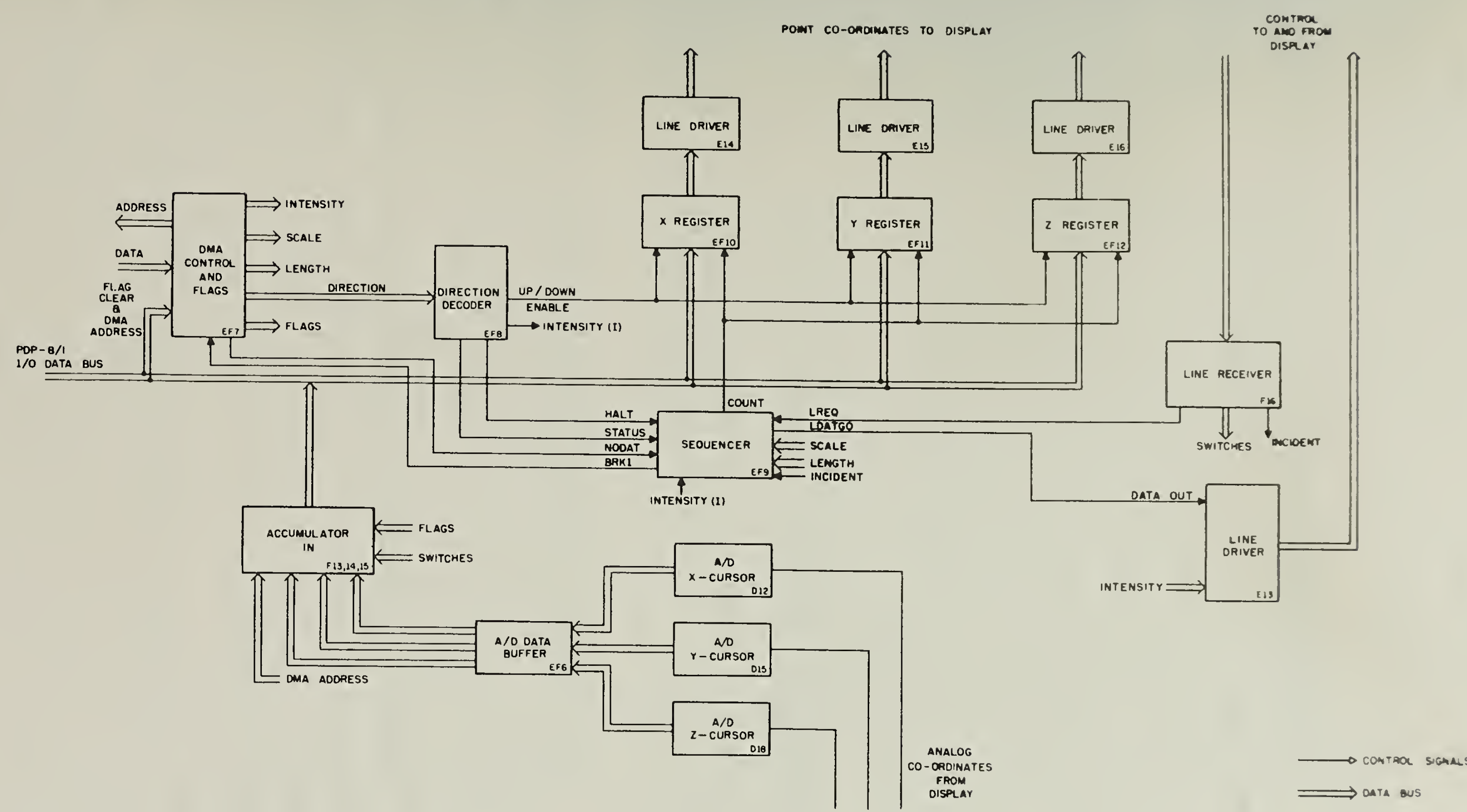



FIG 4 BLOCK DIAGRAM OF PDP-8/1 STEREOMATRIX INTERFACE

The three Accumulator In cards, each controlling four bits, select one of six possible inputs and gate that one onto the PDP-8/I I/O Data Bus.

The interrupt register is contained in the DMA Control card, while the display file completed flag constitutes part of the Sequencer.

The interface is easily modified for similar future applications. For example, only the co-ordinate registers need be modified to change from the sign and magnitude notation presently used. If the new device is in close proximity to the interface, the line drivers and receivers may be removed and replaced with ribbon or similar type cables.

### 3.4 Line Generator Algorithm

The line generator algorithm is the Sequencer card and is flowcharted in Figure 5 with an accompanying definition of terms in Table 1.

Data transfers and point generation rates of the Sequencer are controlled by two external signals: LREQ and LDATGO. To initiate a transfer the display raises LREQ (see Figure 4). With new co-ordinate values, the interface responds with LDATGO which the display uses to gate the data into its registers. It then drops LREQ which automatically clears LDATGO at the interface and the transfer is completed. The Sequencer uses two internal signals to determine the present state of the transfer operation. One signal, $\mathrm{LFREE} = \overline{\mathrm{LREQ}} + \mathrm{LREQ}.\overline{\mathrm{LDATGO}}$, is high whenever the display is not in the process of strobing co-ordinate values into its registers. The second signal, $\mathrm{LRDY} = \mathrm{LREQ}.\overline{\mathrm{LDATGO}}$ is high only when the display is requesting more data and the interface

has not responded. These signals ensure correct sequential operation for all transmission rates.

| | |
|---|---|
| NODAT | is set to "1" if another display command is required from memory. It is cleared after the data is available. |
| BRK1 | is set to initiate DMA transfer. |
| HALT | is "1" if the display command is HALT. |
| LFLAG | the interrupt flag for the display file done. |
| STATUS | is "1" if the display command is LOAD STATUS. |
| LFREE | is set whenever updating the co-ordinate registers will not cause transmission of erroneous data. |
| INT | has value "1" if the current contents of the co-ordinate registers have been plotted. The algorithm prevents double intensification of identical sequential points, e.g. last point of a line and first of next one are identical. |
| I | is the intensity ON/OFF bit of a display command. A value of "1" implies ON. |
| LRDY | set when display is requesting more data. |
| LDATGO | a transition to high signals the display to gate in new co-ordinate values. |
| CNTO | is "0" when LLENGTH contains zero; otherwise, it is "1". |
| SCALER | a 2-bit register compared with SCALE to control number of register increments per transfer. |
| LLENGTH | 6-bit register containing length of line left to plot. |
| SCALE | the scale value (2-bits) held in display status register. |

Table 1. Signal Definitions for Figure 5

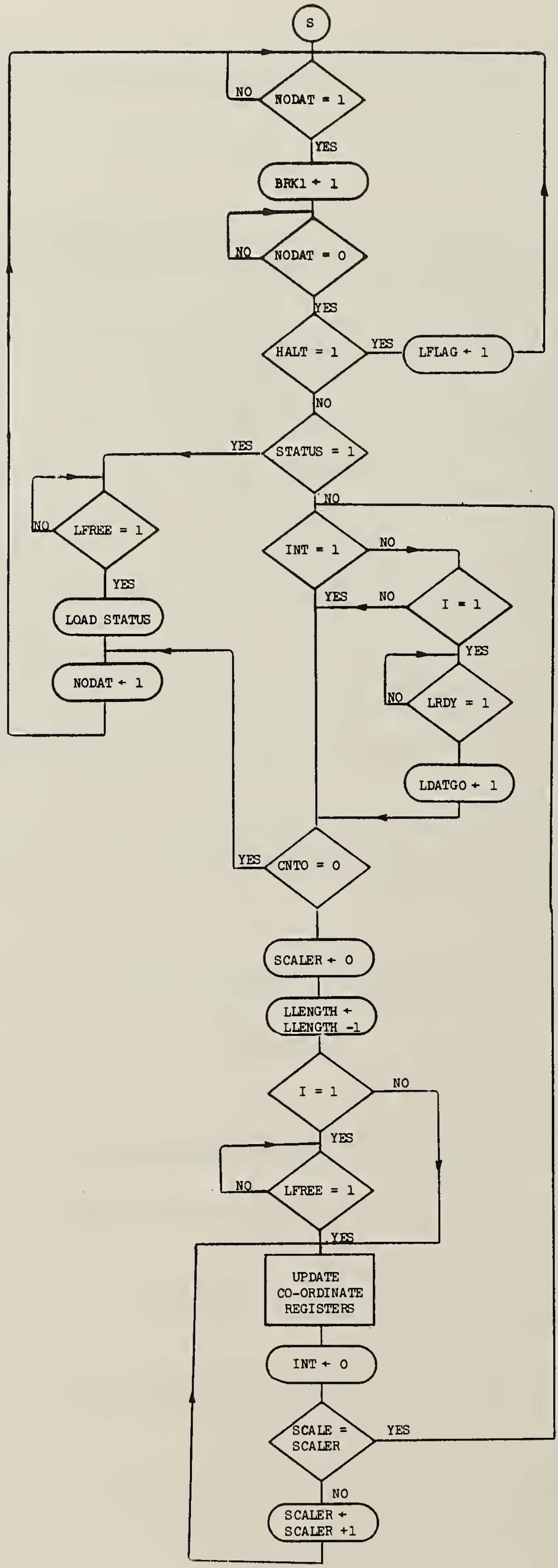



Figure 5. Line Generator Algorithm

# 4. SOFTWARE SUPPORT

## 4.1 Introduction

The Stereomatrix display system was developed to investigate the projection of three-dimensional, computer drawn images. No specific application was being considered while implementing this system. Rather, a study of user/computer communications was needed to evaluate possible types of user/computer controls required in this environment. Consequently, in designing the software support, no effort was made to incorporate any semantics into the graphic structure. The graphics system supports only a syntactical structure and any implied semantics to the user is only in the form, "What you see is what you get."

The display hardware includes controls for manipulating only the entire picture. The software extends this power by facilitating adjustments of both subpictures and elements (defined in next section). In addition, point identification is extended upward to include element and subpicture selection. The cursor controls and user control box switches are sufficient for implementing drawing routines, since no semantic information is required by the graphics package.

The following sections discuss the graphics data structure, a sketch routine and system software implementation.

## 4.2 Graphics Data Structure

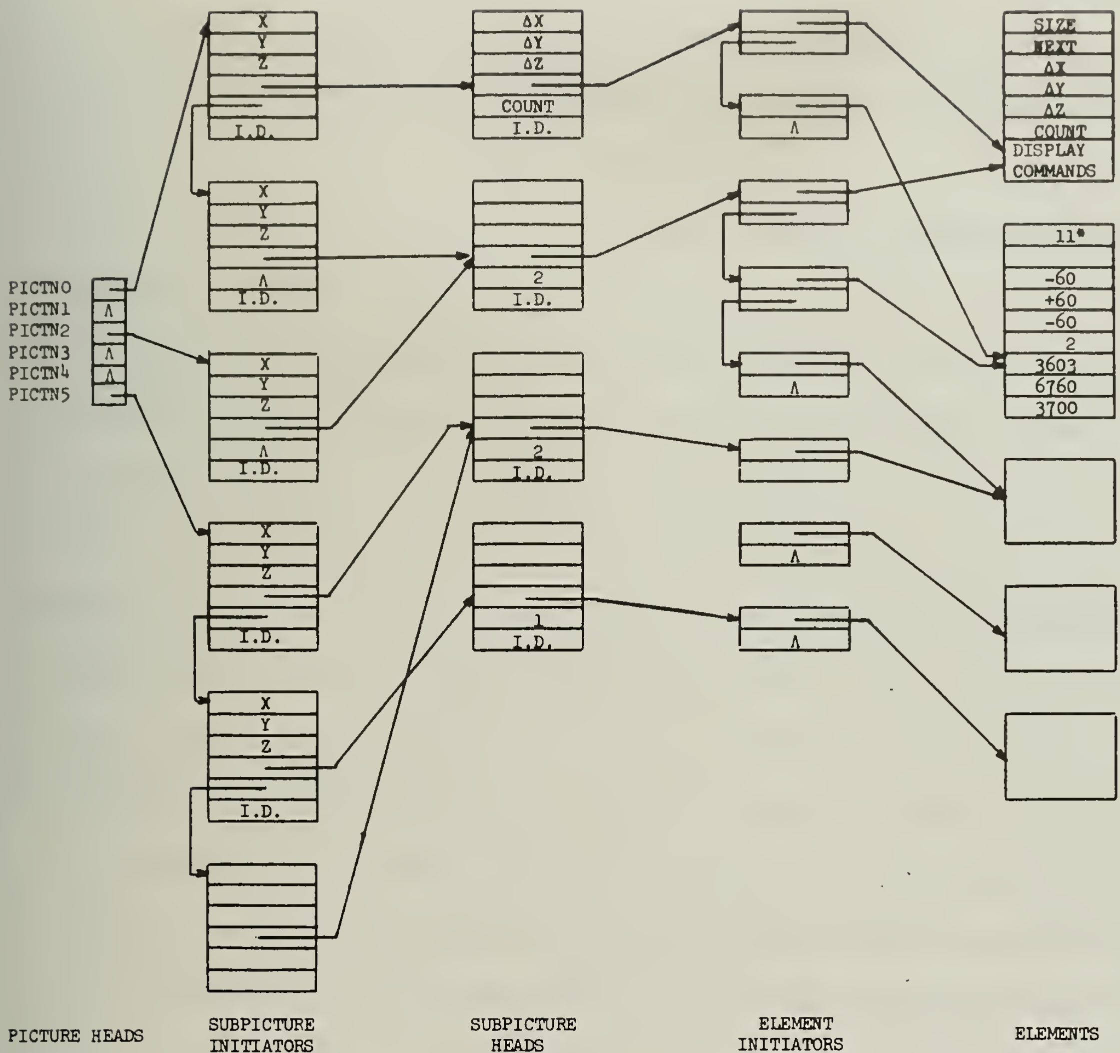
A diagram of the data structure is shown in Figure 6. It contains all the information required to initialize the co-ordinate registers, load status, and plot lines. This structure is separated

into five levels: picture heads, subpicture initiators, subpicture heads, element initiators, and elements.

Picture Heads: Up to six pictures are held in storage and are named PICTNO through PICTN5. Only PICTNO is displayed; the others store images which are displayed by copying to PICTNO. Each picture has one 1-word head which points to a list of subpicture initiators. The picture heads are stored in fixed memory locations and may contain a null pointer (binary zero). If PICTNO is null, nothing is displayed.

Subpicture Initiators: A unique, singly linked list of subpicture initiators exists for each picture head containing a non-zero pointer. The initiator provides new co-ordinate register values for positioning the subpicture. In addition, it provides a pointer to the subpicture head, a pointer to the next initiator and an identification field (I.D.). The I.D. fields are not currently used and were incorporated to allow future expansion of the structure.

Subpicture Heads: The subpicture incorporates one or more picture lines (elements) into a graphical unit. The subpictures are position-independent since the co-ordinate registers are never reloaded. Repositioning of the beam from the end of one line to the start of the next is performed by plotting lines with the intensity OFF. The first three fields of the subpicture head are the avial components of a vector from the initial point to the final co-ordinate of the subpicture. A pointer to a list of element initiators, a COUNT field, and an I.D. field completes the subpicture head. The COUNT field contains the number of subpicture initiator




* All numbers in octal

Figure 6. Graphics Data Structure

pointing to this subpicture. As references to a subpicture are removed, the COUNT is decremented (a subpicture may appear more than once in a picture and in one or more pictures). When this value becomes zero, the subpicture is deleted.

<u>Element Initiators</u>: Every subpicture head points to a list of one or more element initiators. The first field of the initiator contains the address of an element and the second field point to the next initiator. This list is unique to each subpicture head and is deleted with it.

<u>Elements</u>: The elements are variable lengthed files containing several control fields and a sequential list of display commands. The first two fields, SIZE and NEXT, are used by the storage allocation routines. The $\Delta X$, $\Delta Y$, and $\Delta Z$ fields contain the components of a vector from the beginning to the final co-ordinate of the element. The COUNT field again determines when the element is no longer required. An element may also appear more than once in a subpicture and in more than one subpicture.

The low level software (further explained in a subsequent section) contains routines for insertion, deletion, and modification of nodes and display files. The plotting rate of the graphics system is not degraded by the complexity of the data structure since list transversal operates in parallel with line generation. A subpicture is repositioned by modifying the co-ordinate values in the subpicture initiator. Modification to a subpicture causes all displayed instances

to be modified. The unintensified lines which permit subpictures to be position independent are "plotted" at 400 ns. per point and do not significantly decrease the amount of displayable information. The alternative of reloading the co-ordinate registers would decrease the simplicity of subpicture control and would require more processor time. In addition, many subpictures will be localized images containing short, unintensified lines.

The graphics structure simplifies many operations and utilizes storage efficiently. The vector in the subpicture head facilitates the concatenation of another element to the subpicture. Duplication of a subpicture only requires the addition of another subpicture initiator, adjustments to several pointers, and an increment to the COUNT in the subpicture head.

## 4.3 Stereomatrix Software

A drawing package was developed to evaluate the interactive controls available and to permit experimentation with possible future graphical applications. An understanding of the data structure is essential since the picture building procedures use this as a basis. Only PICTNO is modifiable since it is the only image displayed.

The Stereomatrix user communicates with the system via the switches on the user control box, the cursor joy stick, and its associated switches. The user control switches, numbered 1 to 5 (left to right), set bits in a buffer register. The sixth switch generates a computer interrupt causing the program to read this buffer and initiate a response. In the following discussion, "BTj" denotes

pressing switch "j" and then the interrupt switch. If a combination of switches is required, all must be depressed before requesting the interrupt. IONLY signifies an interrupt with no other switches previously set.

There are three switches associated with the operation of the cursor. Pressing the switch marked "M" will cause a cursor interrupt which alerts the program of the current cursor position. When the "C" switch is pushed, an incident interrupt will occur whenever the cursor is in close proximity to a line on the screen. This feature is disabled when "D" is pushed. In the explanation below, the letters "M", "C", and "D" denote pressing the switches marked by these symbols. The controls for rotation translation and scaling are also adjacent to the cursor and their operation is self-explanatory.

Nine modes of operation are controlled by the user switches with external inputs being interpreted uniquely for each mode. The IONLY input from the user switches will terminate any mode and force entry to mode zero from which all other modes may be entered. The remaining eight modes function as follows:

<u>Mode 1: Straight Element Drawing</u>

BT1 enters this mode. M locates one end on the straight line at current cursor position. The other end follows the cursor. M again completes the line at its last position. Another line is started by M and IONLY will exit back to mode zero. In addition to the element, a subpicture initiator, subpicture head, and element initiator are added to the data structure of PICTNO.

Mode 2: Cursor Element Tracing

BT2 enters mode. M initiates trace at current cursor position and it follows the path of the cursor. M completes this trace and M again will initiate another. IONLY exits back to mode zero. The same data structure as in mode 1 is added to PICTNO.

Mode 3: Element Identification and Deletion

BT3 enters mode. C enables detection hardware. The element identified by the cursor is constantly flashed on and off until either another element is identified or other actions are taken. BT3 will delete an identified element. If the element deleted is the only one in the subpicture, then the mode is forced into subpicture deletion (mode 4). IONLY exits from this mode and returns any identified element to its normal state.

Mode 4: Subpicture Identification and Deletion

BT4 enters mode. C enables detection hardware. Subpictures are identified in a similar manner to elements. BT4 will delete an identified subpicture. The subpicture initiator will be deleted from the list of initiators for PICTNO and if COUNT field has value "one" in the subpicture head, then it also will be deleted. IONLY exits from mode and returns any identified subpictures to their normal state.

Mode 5: Subpicture Assimilation

BT5 enters mode. C again enables detection hardware. A host subpicture must be identified with the cursor and BT5. Other subpictures will be spatially concatenated to this one. The host subpicture will constantly flash on and off as will the next identified subpicture. BT5 will merge the newly identified subpicture with the host, creating a new host subpicture. The subpicture initiator for the second identified subpicture will be deleted. Another identified subpicture may now be concatenated. IONLY exits from this mode. All instances of the host subpicture will be modified, but any other instances of the merged subpictures will not be changed.

Mode 6: Translation

BT1 and BT2 and one other switch enter this mode. If this other switch is BT3, the entire picture is moved by the cursor, or a subpicture with BT4 or a copy of a subpicture with BT5. The incident control must be enabled by C. The first point detected will serve as the reference and will follow the cursor.

Mode 7: Storing Pictures

BT1, BT2, BT3, and BT4 enter this mode. Only PICTNO is displayable and modifiable, and hence, it must be savable and retrievable. BTj generates a copy of PICTNO pointed to by PICTNj. The previous PICTNj is deleted and only new subpicture initiators are created for the copy. The mode automatically returns to zero after PICTNO has been copied. IONLY aborts this mode with no copy saved.

Mode 8: Retrieving Pictures

All switches set enter this mode. BTj concatenates PICTNj to PICTNO. If PICTNO is null, then only PICTNj will be displayed. The previous PICTNj is not destroyed.

## 4.4 Software Implementation

The software is organized into two levels to facilitate the programming and expansion of the system. The lower level is highly dependent upon the data structure, display control features, and other I/O conditions. Routines in this section perform storage allocation, line generation, list manipulation, and interrupt handling for the display and interval clock. These procedures and the display data structure occupy the bottom 4K of memory. The second level (or high level) is the application software for the display. The logical operation of these routines is clearer and more concise since lower level procedures are invoked which handle device and data structure subtleties. All program coding is in assembly language.

Two storage allocation routines are incorporated in the lower level control—one for fixed length nodes and one for variable length elements. The two and six word nodes are allocated sequentially from opposite ends of a continuous block of storage. A singly linked list is maintained for each size of free nodes. When this list is empty, another node is taken from the storage not yet claimed. Overflow results when the list of free nodes is empty and all storage has been claimed. Element memory allocation uses a singly linked list of free storage with each continuous block containing its size and a pointer to the next one. A specific core requirement is made and the first block of sufficient size is utilized.

Software for handling the 16 ms. interval timer is incorporated into the lower level. A maximum of six variable lengthed intervals can be controlled by this routine. Every half second an error recovery routine checks for pathological conditions in the system. If PICTNO is not null and has not been displayed in the interval, the recovery procedure forcibly starts the interface. This feature proves very valuable in a system where initially neither the software nor hardware is fully error free.

# 5. CONCLUSIONS

In present 2-D graphical systems, the display is a functional tool which serves as a communications link between the computer and user. The 3-D graphical system potentially offers more to the user. The display is not as much a tool used in order to communicate with the computer, but in effect, it becomes the actual object of communication. The user is more fully able to communicate directly with the displayed figure--the computer now becomes the functional tool, acting only as the "brain" for the display. I will suggest a modification to a proposed change to Stereomatrix that would improve the quality of the displayed images and methods to attain the level of user/display rapport alluded to above.

A proposed modification to the display for automatic generation of lines would greatly increase the amount of flicker-free material that can be displayed. Due to acoustical delays in the laser deflecting components, approximately seven microseconds is required between point intensifications. The distance between two successive points is not important. If the delay between intensifications is decreased, a smear results as portions of the right move to the new position. By decreasing the delay for continuous lines, the rate of plotting will increase and the resulting smear will enhance the quality of picture. The interface will require redesigning to accommodate a display controlled line mode; however, the plotting rate of curved lines will not increase. By utilizing one of the free bits in the display status register to select a display rate, the program could plot any continuous line at the higher rate. The interface would not be changed and only minor modification would be required to the display.

For a computer-driven display to react dramatically in a real-time environment, it requires the assistance of additional logic. Automatic rotation of graphic images is one of the most desired functions for a display system. More computing power is required for performing these calculations in real-time than is available from a minicomputer. The Stereomatrix does have rotational type powers, but the computer neither knows nor controls what functions are performed. It can only send a string of co-ordinates to be intensified and the coefficient generator modifies this input.

Control of the coefficient generator which initiates rotation, etc., can be given to the computer by permitting it to store and forward inputs from the display control box. The computer can then keep track of the total manipulations performed. The coefficient generator fixes angular frequency for rotation and other variables at a "suitable" constant. Under computer control, the rate of rotation and translation may be varied. In addition, these features may be invoked automatically by the computer in response to other inputs to the system. Since the controlling signals are dc levels very little additional interface control logic would be required to implement this feature.

The display hardware can, at present, rotate a picture only about one of the major axes. With the power available, the computer can affect rotation about any axis. An initial sequence of translations and rotations move the picture so that the desired axis of rotation is on one of the major axes. Then, the desired rotation is performed. The picture is then returned to its initial position by reversing the order and direction of the initial operations. If none of the

intermediate results are displayed, then the picture will appear to rotate around the desired axis.

The 3-D environment of the Stereomatrix display lends itself to more sophisticated dialogues than does the 2-D system. If the display is envisaged as a "window" through which the displayed figure and the user communicate with one another, then both should "see" the other in their respective three-dimensional space. The Stereomatrix display is one-sided in this respect. While the observer has complete freedom of movement to look through the window, the displayed figure has no idea where or what the observer is doing. Consequently, it cannot respond dynamically to his actions. Vision requires the use of a camera, sophisticated software and a large controlling computer. However, if the computer is able to determine the observer's position, then the displayed figure "sees" shadows or fuzzy shapes. Allowing the computer access to the position sensors makes this possible, and in addition, it can calculate direction and rate of movement of the user.

As an example, consider the situation where one displayed figure A always positions itself between the user and a displayed object. As the observer moves, the computer rotates and translates the entire picture, maintaining displayed figure A, the object, and the user directly in line with one another. The observer will sense that displayed figure A can "see" him as it reacts to his movements. Delayed computer responses will give the displayed figures more "human-like" movements.

There are applications where it is desirable to rotate only portions of a picture. The coefficient generator is not designed to operate separately on several sections of a picture concurrently and

could not be easily modified to do so. While translation of subpictures is supported by the graphics software, rotation is not. A modification completely inhibiting perspective-related rotations of specified parts of a picture would present an interesting feature and is illustrated by the following example.

A displayed human figure, Igor, and the observer are staring directly at each other. The observer moves to his left. Normally, he would see the right side of Igor's head and body. By modifying the outputs from the position sensor, only Igor's head will turn to follow the movements of the observer. Now, the observer sees the right side of Igor's body, but Igor's head is still staring "head on" at the observer. In other words, Igor's head would appear to rotate on his shoulders. A similar effect has been observed in certain oil portraits done in such a perspective that the subject's eyes appear to stare at the observer from any position of observation. The usual sensor outputs are utilized while displaying the body and with the head, the position sensor values are modified to position the user on the center axis coming from the display and at the same distance from the display as the body (see Figure 7). If Igor is not displayed at the center of the screen, more complex changes must be made to the modified position sensor outputs.

The Stereomatrix display represents a new direction in computer display systems. It gives the user both three-dimensional vision and personal freedom of movement. Although Stereomatrix has 3-D projectional powers, it has 2-D interactive controls. Its potential as a true user/ display communications system presents a unique challenge for further

development. The suggested modifications will increase its interactive capabilities and help produce a truly dynamic system, thus, lending itself to an improved quality of user/display rapport.

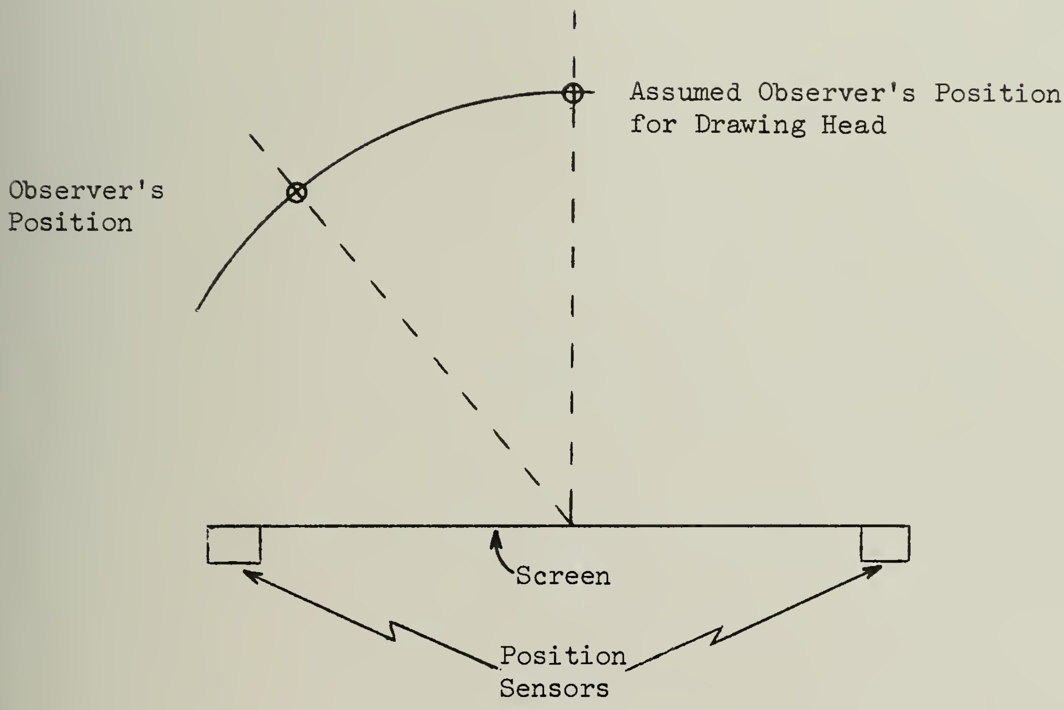



Figure 7. Position for Modified Sensor Outputs

## LIST OF REFERENCES

[1] Kubitz, W. J. and Poppelbaum, W. J. "The Stereomatrix Display," presented at the Society for Information Display International Symposium and Exhibition in Philadelphia, May 4-6, 1971.

[2] Partridge, R. L. "PAGAN, A Three Dimensional Pattern Generator," Department of Computer Science Report No. 464, University of Illinois, Urbana, Illinois 61801, August 1971.

[3] SMALL COMPUTER HANDBOOK, Digital Equipment Corporation, Maynard, Massachusetts, 1967-1968.

# APPENDIX A

# DISPLAY INSTRUCTIONS

| | | |
|---|---|---|
| CLRFLG | 6554 | CLeaR FLaGs |
| DRAW | 6544 | DRAW |
| DSPRGO | 6546 | DiSPlay Reset and Go |
| LDX | 6511 | LoaD X |
| LDY | 6521 | LoaD Y |
| LDZ | 6531 | LoaD Z |
| RDCMA | 6562 | ReaD Complement of Memory Ad |
| RDFLG | 6552 | ReaD FLaGs |
| RDX | 6516 | ReaD X cursor co-ordinate |
| RDY | 6526 | ReaD Y cursor co-ordinate |
| RDZ | 6536 | ReaD Z cursor co-ordinate |
| REDBX | 6561 | REaD BoX |
| RESUM | 6564 | RESUMe |
| SKBF | 6551 | SKip on Buffered Flags |
| SKDF | 6541 | SKip on Display File done |
| STPDSP | 6542 | SToP DiSPlay |

APPENDIX B

The PDP-8/I generates IOP pulses for controlling I/O devices. The six device numbers used by the interface are also referenced by letters as follows: X - 51, Y - 52, Z - 53, A - 54, B - 55, C - 56. The machine instruction DSPRGO (6546) generates pulse IOPA2 followed by IOPA4.

The following comments refer to particular cards.

A/D Data Buffer

The two flip-flops controlling the one-shot prevent gating of new A/D outputs into the buffer during the RDX, RDY, and RDZ instructions.

Sequencer

The Sequencer has seven states called SEQ0 through SEQ6. The transition between states is controlled by a 4-input NAND gate whose output clears the flip-flop of the previous state and sets the one of the next simultaneously. For a state transition to occur, the RUN flip-flop and the required Boolean condition must be "1". In addition, to maintain correct sequential operation, the flip-flop of the state being left must be set and the signal that sets it must have returned to its normally high level. The Sequencer rate is determined by the controlling Boolean condition up to the maximum rate determined by circuit delays.

A/D Converter

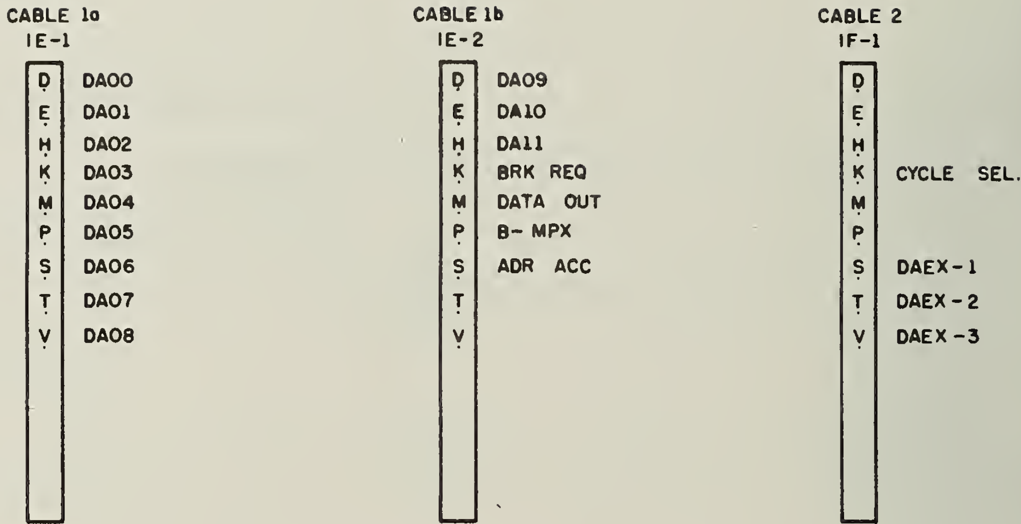
The STROBE input (positive pulse) initiates a conversion. The BUSY output rises with STROBE and drops when the conversion is completed. Maximum conversion time is 50 microseconds with an input range of $\pm 5$ volts. Calibration is as follows:

1. With cables to Stereomatrix removed, connect a pulse generator to the STROBE pin. The generator should produce a 3V pulse of 1 microsecond duration and a period of approximately 100 microseconds.

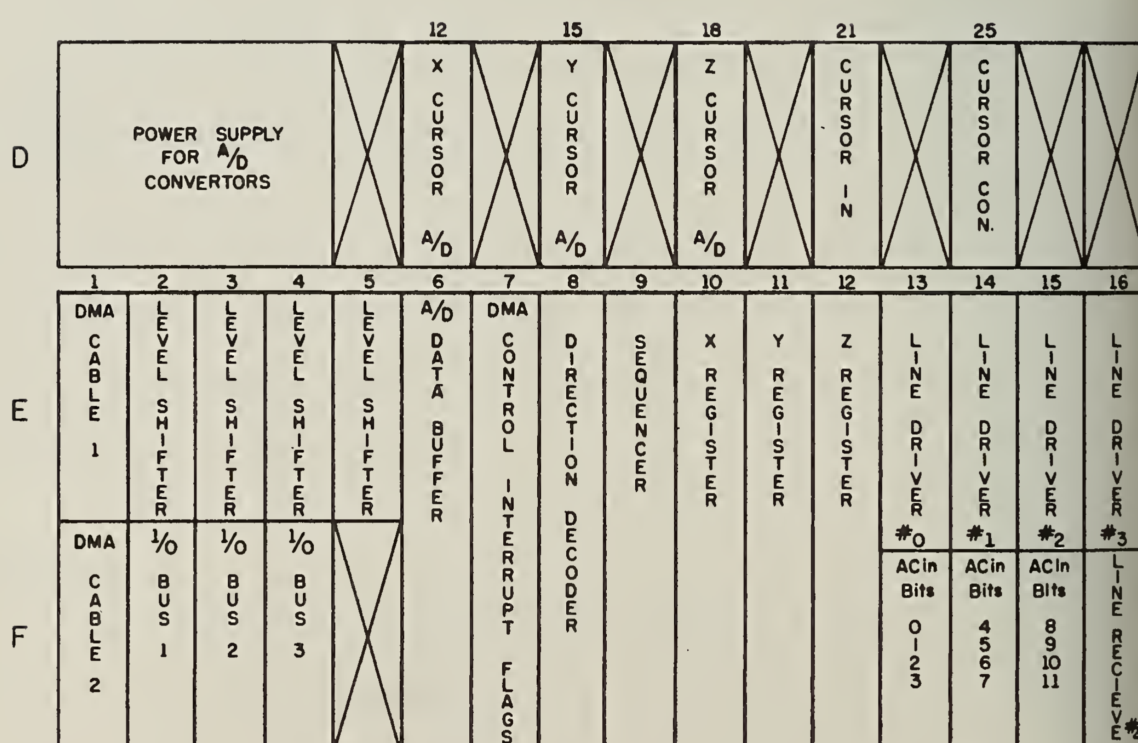
2. Load the following program to observe A/D output in AC register on PDP-8/I console.

```
        CLA
        TAD     (-400
        DCA     TIMER
        RDX                     / or RDY or RDZ
        ISZ     TIMER
        JMP     .-1
        JMP     .-6
```

3. Ground ANA INPUT and adjust the OFFSET pot (200kΩ) until the output code reads 0111111111XX. Then, apply -5.00V to the input and adjust the 2kΩ pot for 0000000001XX.




DMA CABLES




CARD LAYOUT

I/O BUS 1

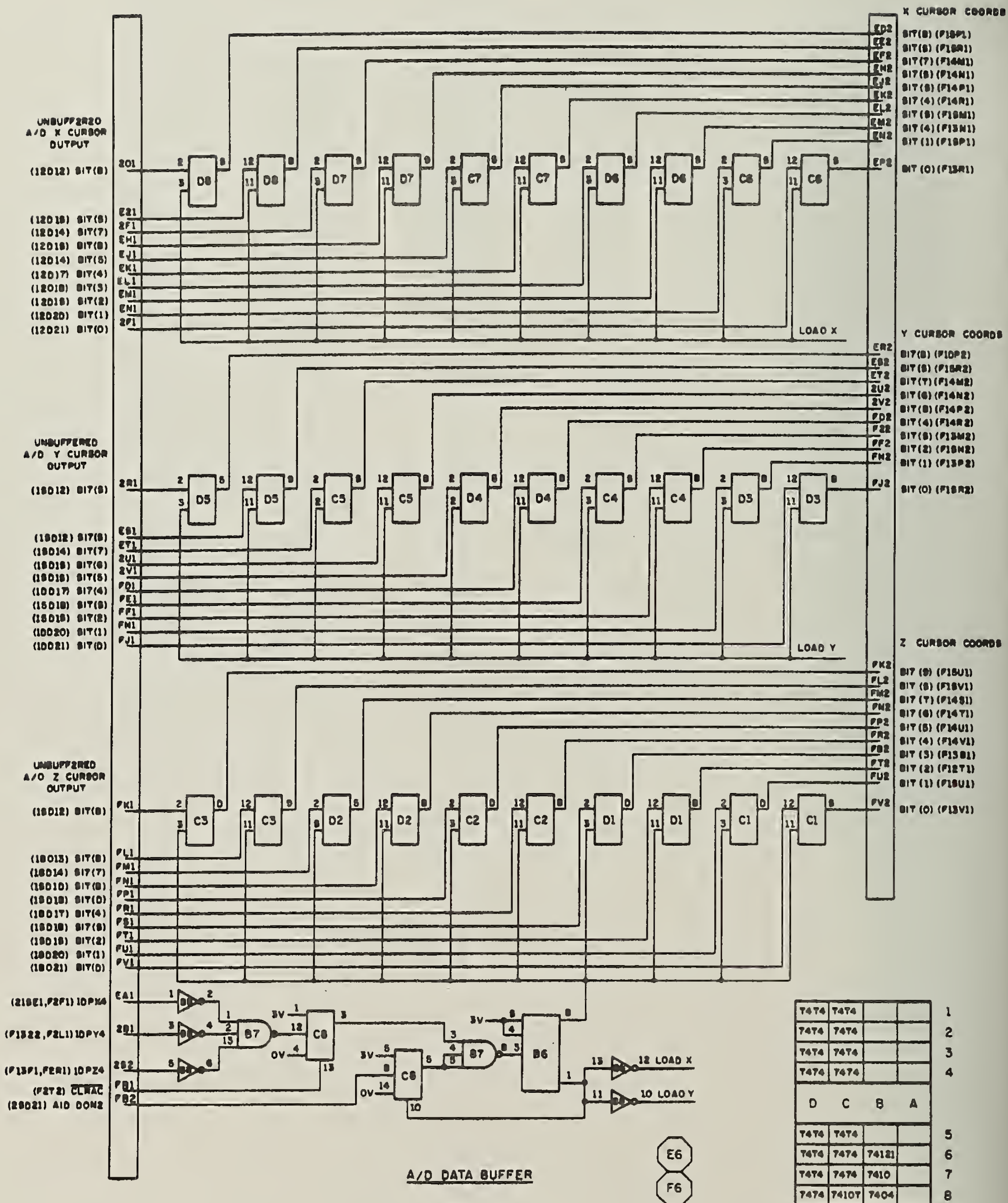
| | |
|---|---|
| IOPX1 - F2D1 | IOPB1 - F2D2 |
| IOPX2 - F2E1 | IOPB2 - F2E2 |
| IOPX4 - F2F1 | IOPB4 - F2F2 |
| GRND - F2H1 | GRND - F2H2 |
| IOPY1 - F2J1 | IOPC1 - F2J2 |
| IOPY2 - F2K1 | IOPC2 - F2K2 |
| IOPY4 - F2L1 | IOPC4 - F2L2 |
| GRND - F2M1 | GRND - F2M2 |
| IOPZ1 - F2N1 | BTS3 - F2N2 |
| IOPZ4 - F2P1 | GRND - F2P2 |
| IOPZ4 - F2R1 | $\overline{\text{SKIP}}$ - F2R2 |
| GRND - F2S1 | GRND - F2S2 |
| IOPA1 - F2T1 | $\overline{\text{CLRAC}}$ - F2T2 |
| IOPA2 - F2U1 | $\overline{\text{INTERRUPT}}$ - F2U2 |
| IOPA4 - F2V1 | INIT - F2V2 |

I/O BUS 2

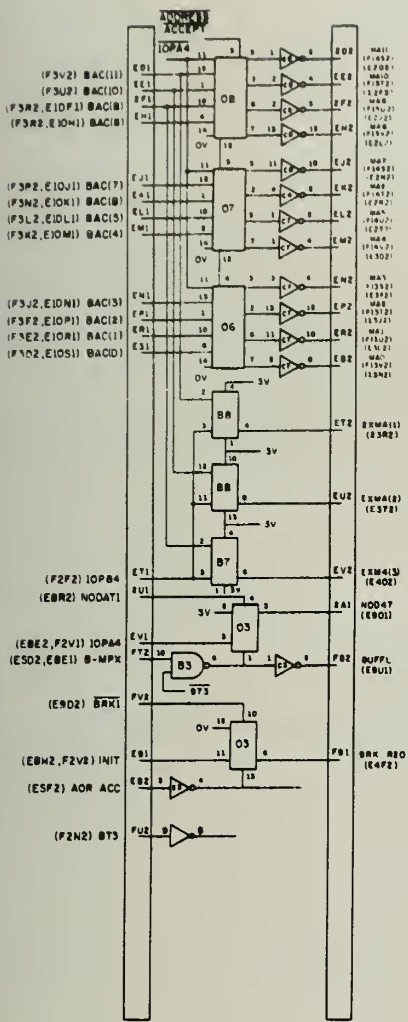
| | | | |
|---|---|---|---|
| BMB(0) | - F3D1 | BAC(0) | - F3D2 |
| BMB(1) | - F3E1 | BAC(1) | - F3E2 |
| BMB(2) | - F3F1 | BAC(2) | - F3F2 |
| GRND | - F3H1 | GRND | - F3H2 |
| BMB(3) | - F3J1 | BAC(3) | - F3J2 |
| BMB(4) | - F3K1 | BAC(4) | - F3K2 |
| BMB(5) | - F3L1 | BAC(5) | - F3L2 |
| GRND | - F3M1 | GRND | - F3M2 |
| BMB(6) | - F3N1 | BAC(6) | - F3N2 |
| BMB(7) | - F3P1 | BAC(7) | - F3P2 |
| BMB(8) | - F3R1 | BAC(8) | - F3R2 |
| GRND | - F3S1 | GRND | - F3S2 |
| BMB(9) | - F3T1 | BAC(9) | - F3T2 |
| BMB(10) | - F3U1 | BAC(10) | - F3U2 |
| BMB(11) | - F3V1 | BAC(11) | - F3V2 |

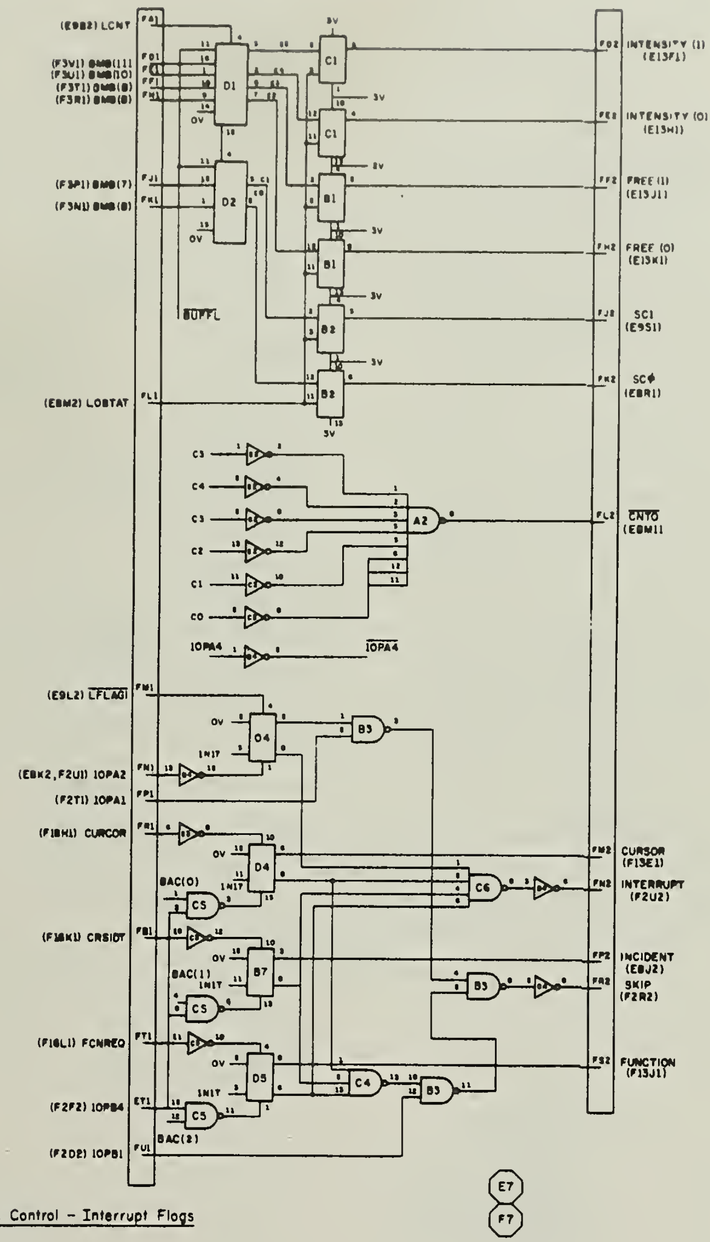
I/O BUS 3

| | |
|---|---|
| ACIN(0) | F4D1 |
| ACIN(1) | F4E1 |
| ACIN(2) | F4F1 |
| GRND | F4H1 |
| ACIN(3) | F4J1 |
| ACIN(4) | F4K1 |
| ACIN(5) | F4L1 |
| GRND | F4M1 |
| ACIN(6) | F4N1 |
| ACIN(7) | F4P1 |
| ACIN(8) | F4R1 |
| GRND | F4S1 |
| ACIN(9) | F4T1 |
| ACIN(10) | F4U1 |
| ACIN(11) | F4V1 |



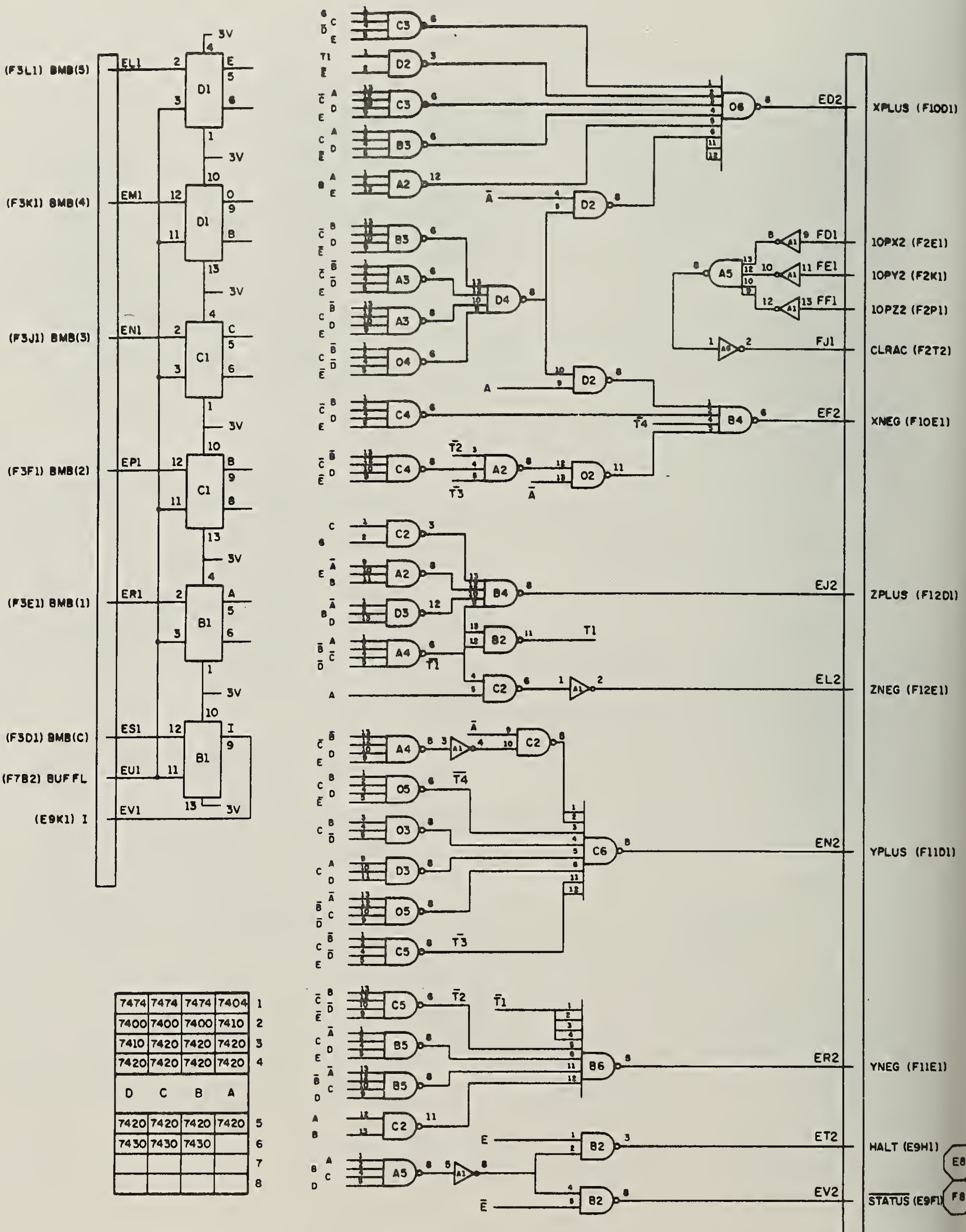

A/D DATA BUFFER





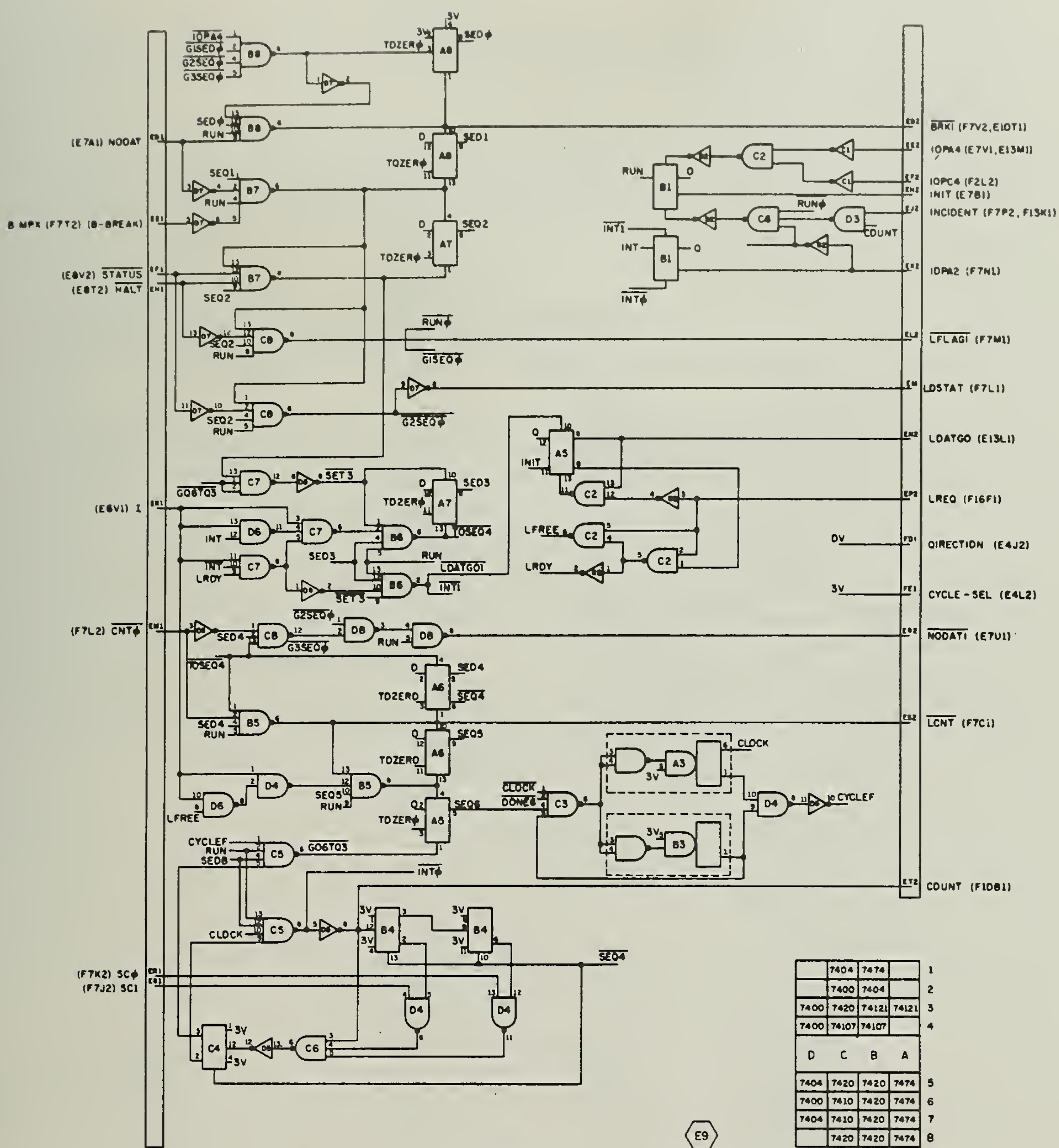
| | | | | |
|---|---|---|---|---|
| 74193 | 7474 | 7474 | | 1 |
| 74193 | 7404 | 7474 | 7430 | 2 |
| 7474 | 7404 | 7400 | | 3 |
| 7474 | 7410 | 7404 | | 4 |
| D | C | B | A | |
| 7474 | 7400 | | | 5 |
| 74193 | 7420 | | | 6 |
| 74193 | 7404 | 7474 | | 7 |
| 74193 | 7404 | 7474 | | 8 |

DMA Control – Interrupt Flags



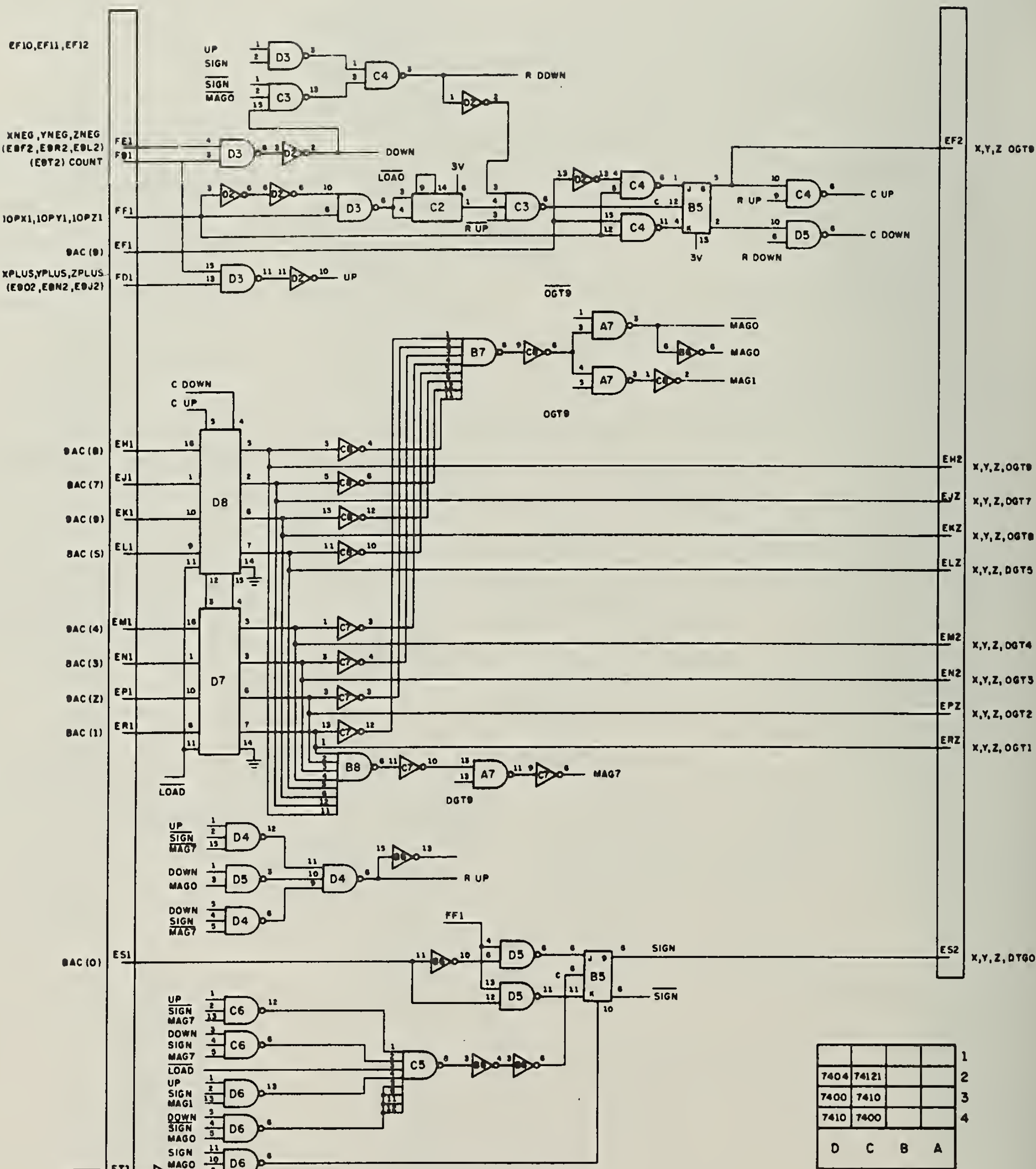

| D | C | B | A | |
|---|---|---|---|---|
| 7474 | 7474 | 7474 | 7404 | 1 |
| 7400 | 7400 | 7400 | 7410 | 2 |
| 7410 | 7420 | 7420 | 7420 | 3 |
| 7420 | 7420 | 7420 | 7420 | 4 |
| 7420 | 7420 | 7420 | 7420 | 5 |
| 7430 | 7430 | 7430 | | 6 |
| | | | | 7 |
| | | | | 8 |

DIRECTION DECODER



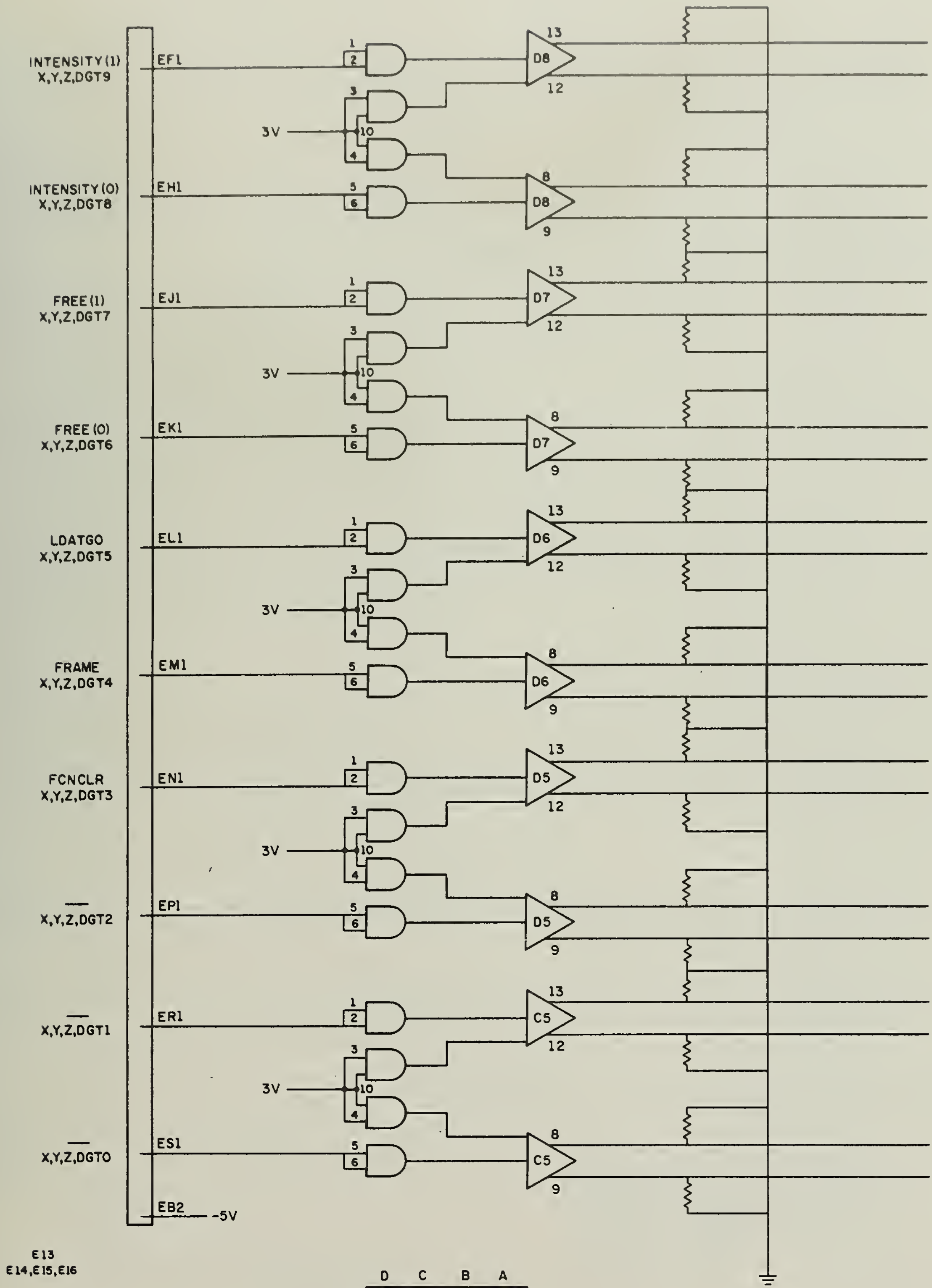

| | D | C | B | A | |
|---|---|---|---|---|---|
| | | 7404 | 7474 | | 1 |
| | | 7400 | 7404 | | 2 |
| | 7400 | 7420 | 74121 | 74121 | 3 |
| | 7400 | 74107 | 74107 | | 4 |
| | 7404 | 7420 | 7420 | 7474 | 5 |
| | 7400 | 7410 | 7420 | 7474 | 6 |
| | 7404 | 7410 | 7420 | 7474 | 7 |
| | | 7420 | 7420 | 7474 | 8 |

SEQUENCER



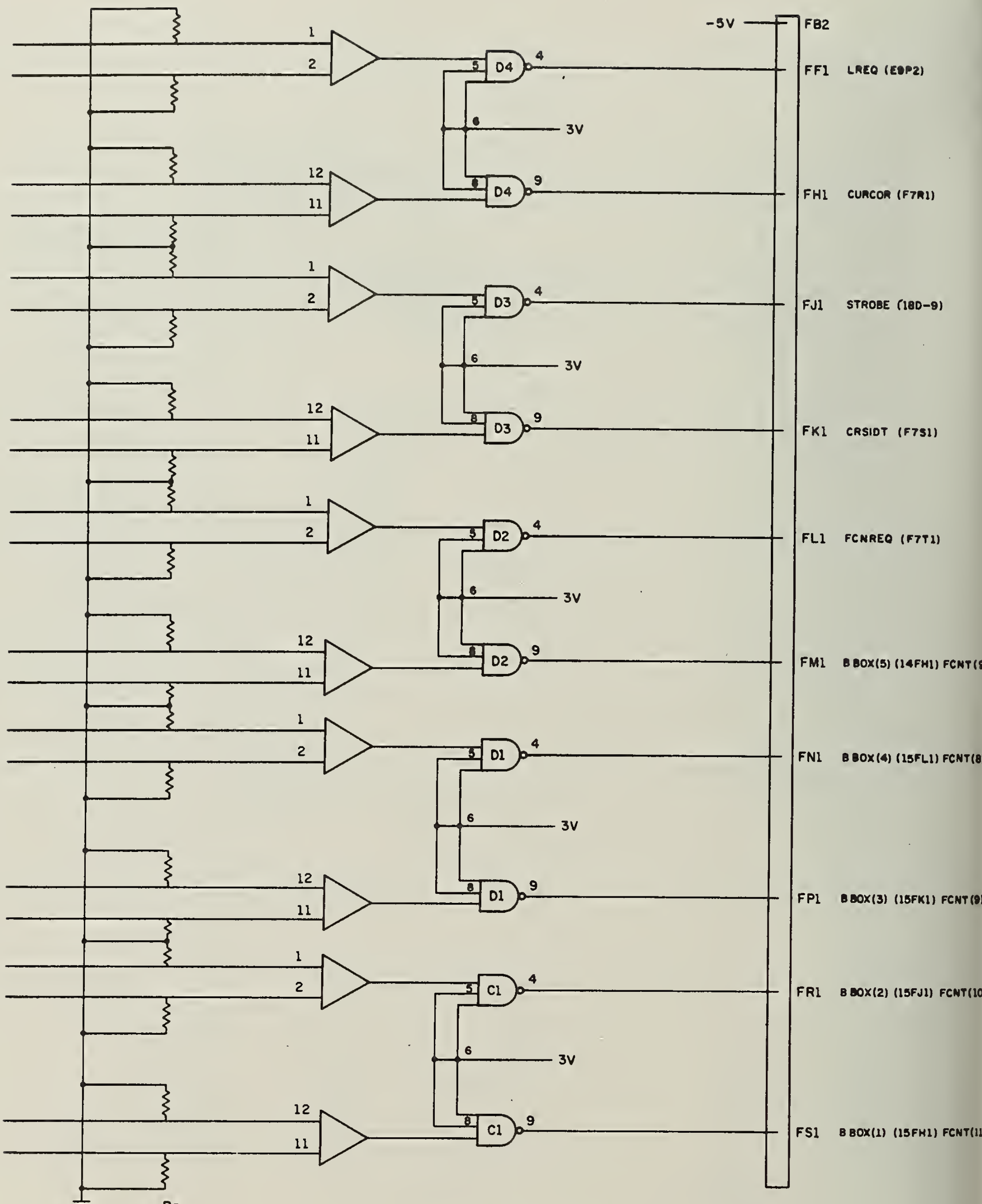

X,Y,Z CO-ORDINATE REGISTER

| D | C | B | A | |
|---|---|---|---|---|
| | | | | 1 |
| 7404 | 74121 | | | 2 |
| 7400 | 7410 | | | 3 |
| 7410 | 7400 | | | 4 |
| D | C | B | A | |
| 7400 | 7430 | 74107 | | 5 |
| 7410 | 7410 | 7404 | | 6 |
| 74193 | 7404 | 7430 | 7400 | 7 |
| 74193 | 7404 | 7430 | | 8 |




| | D | C | B | A | |
|---|---|---|---|---|---|
| | 75109 | 75109 | | | 5 |
| | 75109 | | | | 6 |
| | 75109 | | | | 7 |
| | 75109 | | | | 8 |

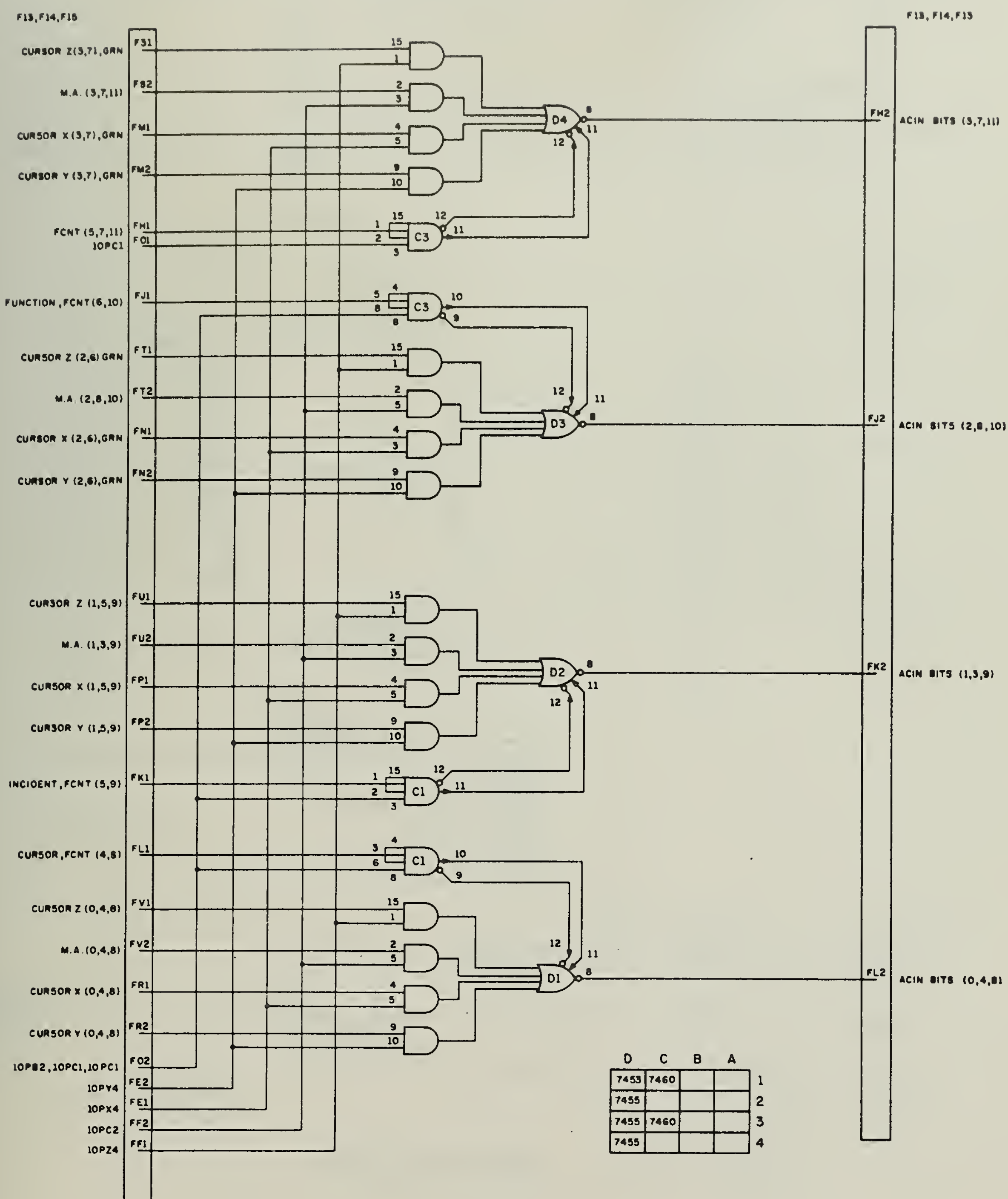
Line Drivers



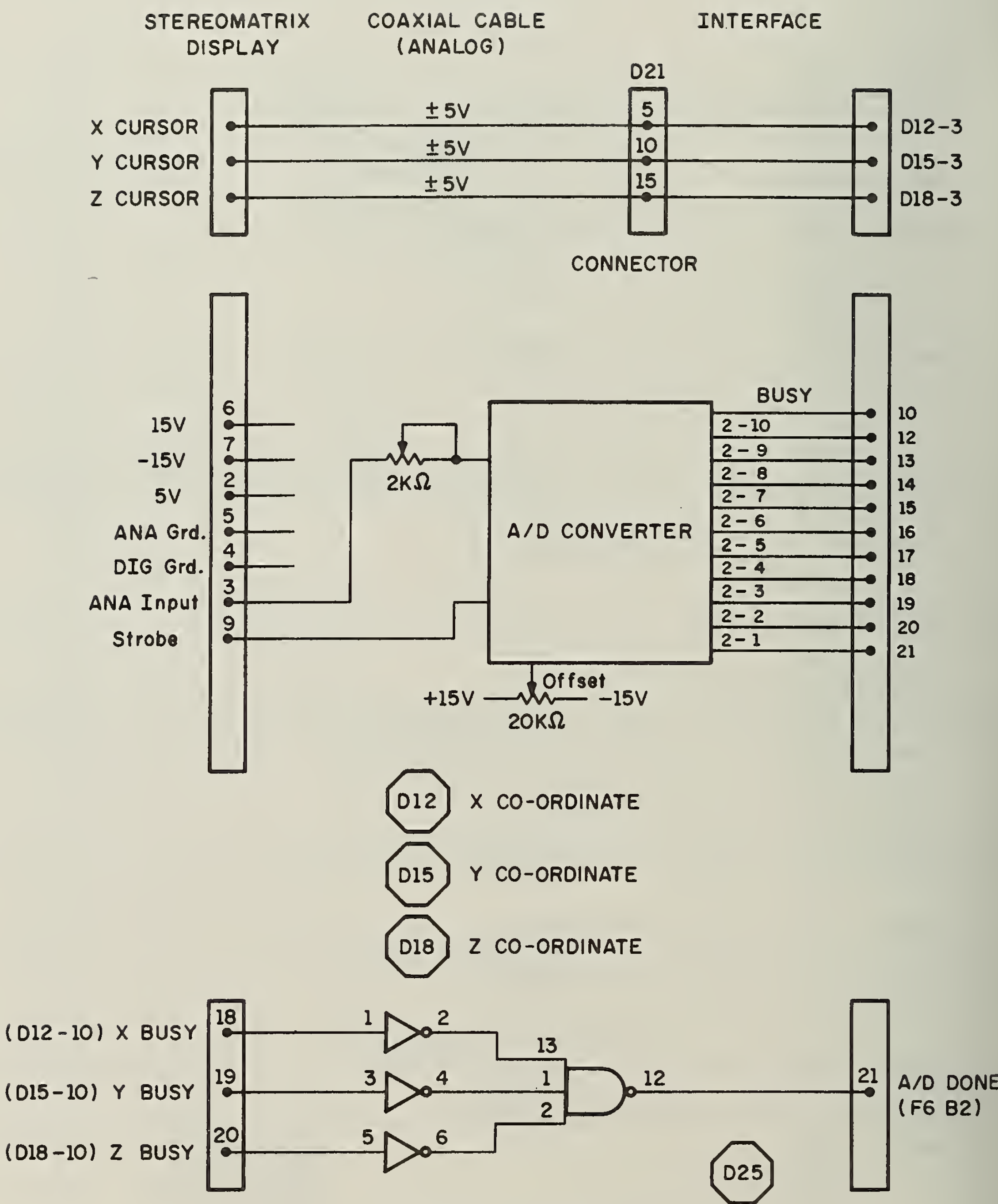

| | D | C | B | A |
|---|---|---|---|---|
| 1 | 75107 | 75107 | | |
| 2 | 75107 | | | |
| 3 | 75107 | | | |
| 4 | 75107 | | | |

Line Receivers

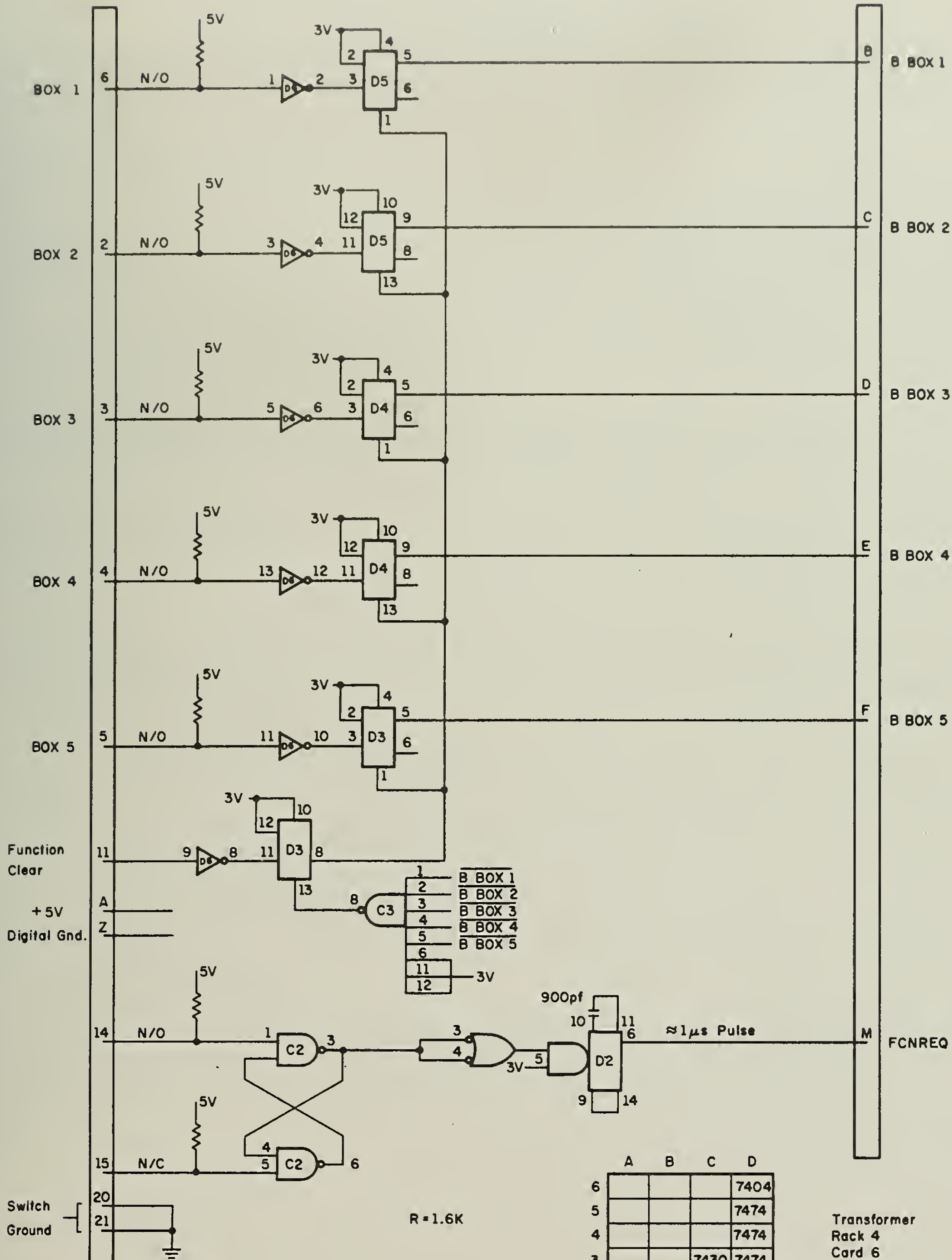
F16




| D | C | B | A | |
|---|---|---|---|---|
| 7453 | 7460 | | | 1 |
| 7455 | | | | 2 |
| 7455 | 7460 | | | 3 |
| 7455 | | | | 4 |




CURSOR CONTROLS




| | A | B | C | D |
|---|---|---|---|---|
| 6 | | | | 7404 |
| 5 | | | | 7474 |
| 4 | | | | 7474 |
| 3 | | | 7430 | 7474 |
| 2 | | | 7400 | 74121 |
| 1 | | | | |

BUTTON CONTROL AND REGISTERS

C-427
(8)
C 3201

# U.S. ATOMIC ENERGY COMMISSION
# UNIVERSITY–TYPE CONTRACTOR'S RECOMMENDATION FOR DISPOSITION OF SCIENTIFIC AND TECHNICAL DOCUMENT

*( See Instructions on Reverse Side )*

| REPORT NO. | 2. TITLE |
|---|---|
| COO-1469-0202 | HARDWARE/SOFTWARE INTERFACE FOR THE STEREOMATRIX DISPLAY |

E OF DOCUMENT (Check one):

] a. Scientific and technical report
] b. Conference paper not to be published in a journal:
Title of conference ______
Date of conference ______
Exact location of conference ______
Sponsoring organization ______
] c. Other (Specify) Thesis

COMMENDED ANNOUNCEMENT AND DISTRIBUTION (Check one):

] a. AEC's normal announcement and distribution procedures may be followed.
] b. Make available only within AEC and to AEC contractors and other U.S. Government agencies and their contractors.
] c. Make no announcement or distrubution.

ASON FOR RECOMMENDED RESTRICTIONS:

MITTED BY: NAME AND POSITION (Please print or type)

C. William Gear, Professor
and Principal Investigator

anization

Department of Computer Science
University of Illinois
Urbana, Illinois 61801

| ature | Date |
|---|---|
| Charles W Gear. | April 13, 1972 |

FOR AEC USE ONLY

C CONTRACT ADMINISTRATOR'S COMMENTS, IF ANY, ON ABOVE ANNOUNCEMENT AND DISTRIBUTION COMMENDATION:

ENT CLEARANCE:

] a. AEC patent clearance has been granted by responsible AEC patent group.
] b. Report has been sent to responsible AEC patent group for clearance.
] c. Patent clearance not required.

| LIOGRAPHIC DATA EET | 1. Report No. UIUCDCS-R-72-508 | 2. | 3. Recipient's Accession No. |
|---|---|---|---|
| itle and Subtitle HARDWARE/SOFTWARE INTERFACE FOR THE STEREOMATRIX DISPLAY | | | 5. Report Date June 1972 |
| | | | 6. |
| uthor(s) Ian MacDonald Cunningham | | | 8. Performing Organization Rept. No. |
| erforming Organization Name and Address Department of Computer Science, University of Illinois, Urbana, Illinois 61801 | | | 10. Project/Task/Work Unit No. US AEC AT(11-1)1469 |
| | | | 11. Contract/Grant No. US AEC AT(11-1)1469 |
| Sponsoring Organization Name and Address US AEC Chicago Operations Office, 9800 South Cass Avenue, Argonne, Illinois 60439 | | | 13. Type of Report & Period Covered Thesis research |
| | | | 14. |

Supplementary Notes


Abstracts

A random-access, three-dimensional laser display called Stereomatrix has been built by a group in the Department of Computer Science at the University of Illinois. Three-dimensional wire figures are displayed by generating separate images for the left and right eyes. The light from the laster is split into two beams, and then the polarization of the left beam is rotated 90 degrees. Both beams are deflected along the x and y axis, resulting in a double image. The observer wears glasses with oppositely polarized lenses which give the visual effect of a third dimension. The observer's position is sensed by an infrared light source contained on the glasses. Movements of the observer are detected and automatic redisplaying of the figure as it would appear to the observer from the new position occurs. The observer also may scale, rotate, and translate the picture under complete hardware control. A three-dimensional cursor is also displayed by the hardware.


Key Words and Document Analysis. 17a. Descriptors

random-access
three-dimensional
laser display
stereomatrix
polarization

Identifiers/Open-Ended Terms

COSATI Field/Group

| Availability Statement | 19. Security Class (This Report) | 21. No. of Pages |
|---|---|---|
| unlimited distribution | UNCLASSIFIED | 57 |
| | 20. Security Class (This Page) UNCLASSIFIED | 22. Price |